Title : Heteroatom Engineering of Nitrogen and Phosphorus Co-doped Porous Carbon from Peanut Shells Toward High-Performance Sodium-Ion Battery Anodes

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ABSTRACT

Porous carbon materials derived from agricultural waste have attracted significant attention as anode materials for sodium-ion batteries (SIBs) due to their sustainability, low cost, and favorable physicochemical properties. In this study, peanut shells were utilized as an abundant and renewable carbon precursor and converted into heteroatom-doped porous carbon through microwave-assisted KOH activation, followed by hydrothermal treatment and high-temperature pyrolysis under an inert atmosphere. Chitosan and phytic acid were employed as nitrogen and phosphorus dopant sources, respectively, enabling effective heteroatom incorporation into the carbon framework. The phytic acid content was systematically adjusted to regulate the structural and compositional characteristics of the resulting materials. The optimized samples exhibited a well-developed hierarchical porous structure, enlarged interlayer spacing, and increased structural disorder, which are beneficial for facilitating sodium-ion diffusion and charge storage. X-ray diffraction (XRD) analysis confirmed the formation of predominantly amorphous carbon with broad diffraction features, while Raman spectroscopy revealed defect-rich disordered graphitic domains. Scanning electron microscopy (SEM) demonstrated an interconnected porous morphology, and energy-dispersive X-ray spectroscopy (EDS) confirmed the presence and uniform distribution of

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nitrogen and phosphorus dopants throughout the carbon matrix. These structural and compositional characteristics highlight the effectiveness of heteroatom engineering and demonstrate a sustainable strategy for converting peanut shell waste into high-performance heteroatom-doped porous carbon anodes for sodium-ion battery applications.

Keywords: Sodium-ion batteries, Biomass-derived porous carbon, Peanut shell, Heteroatom doping, Nitrogen and phosphorus co-doping, Microwave-assisted activation, Anode materials

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